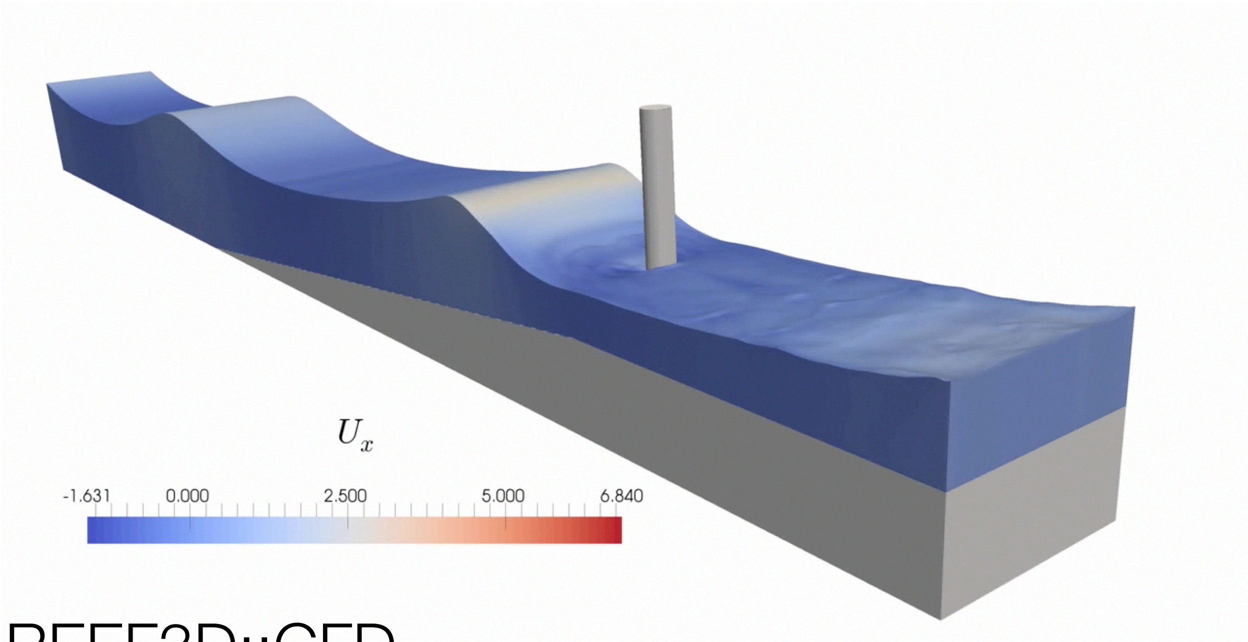
Rapid nonlinear numerical modelling and force calculation, digitalisation skills in education at NTNU

Weizhi Wang
Researcher
Department of Civil and Environmental Engineering
Research group Marine Civil Engineering
NTNU

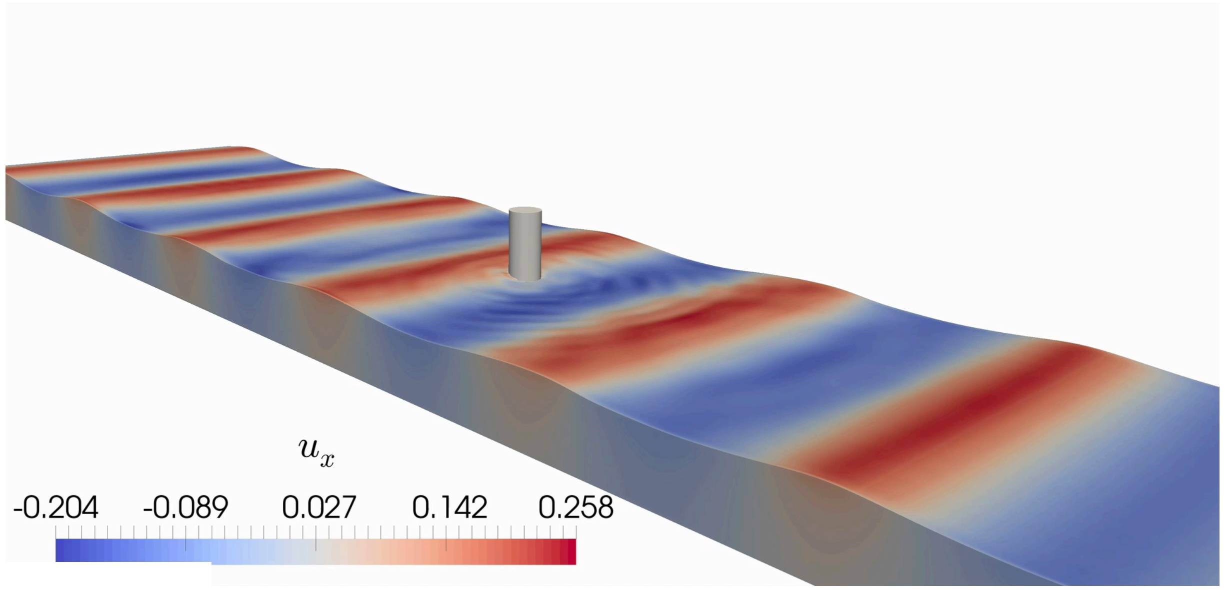
Need for speed

- Industry needs fast solutions
- Students needs fast toolbox
- Training of digital skills
- More efficiency and less hardware-dependency

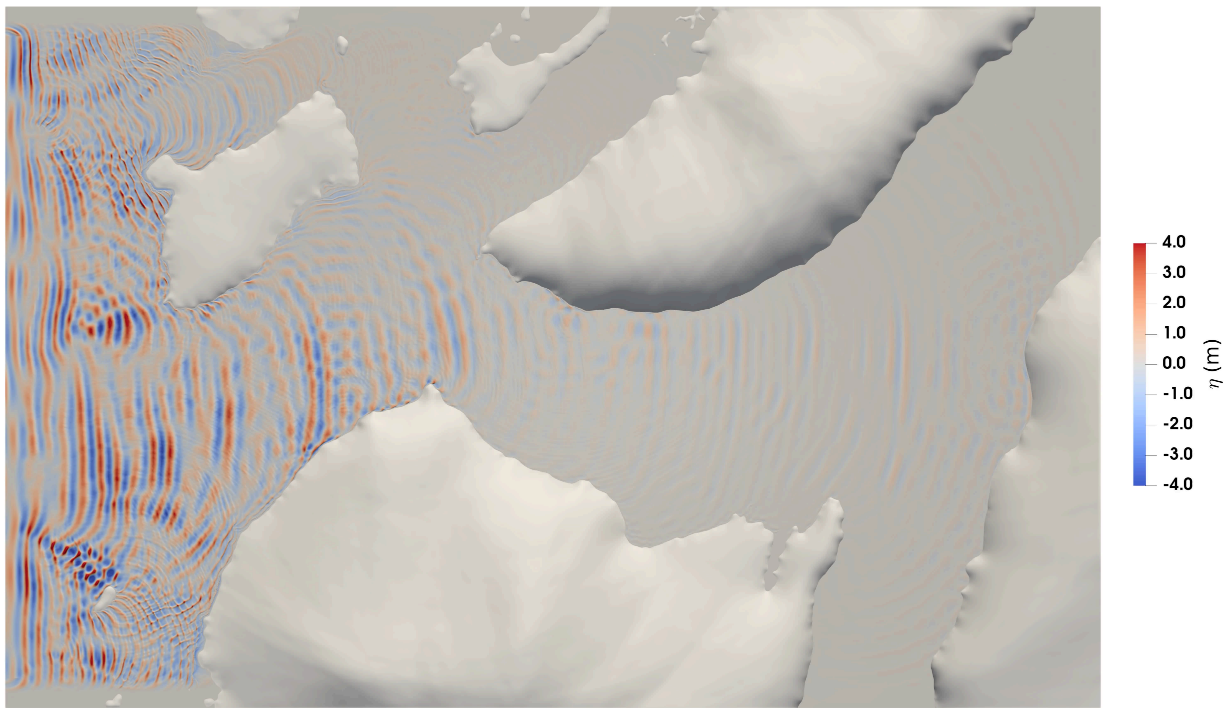
REEF3D : Multi-scale extension



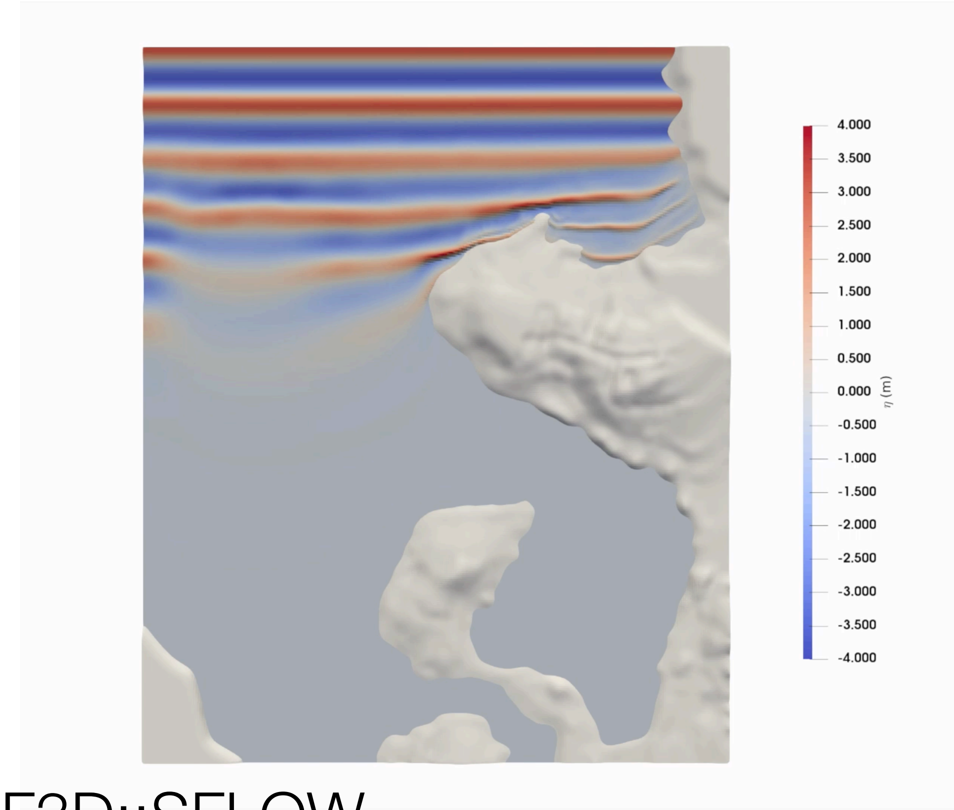
REEF3D::CFD



REEF3D::NSEWAVE



REEF3D::FNPF



REEF3D::SFLOW

Governing Equations: REEF3D::CFD

Incompressible RANS Equations:

$$\frac{\partial U_i}{\partial x_i} = 0$$

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[(\nu + \nu_t)\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right] + g_i$$

- Temporal Discretisation: 3rd-order TVD Runge Kutta
- Spatial Discretisation: 5th-order WENO
- Pressure Solution: Projection Method, PPE: PFMG HYPRE

Governing Equations: REEF3D::FNPF

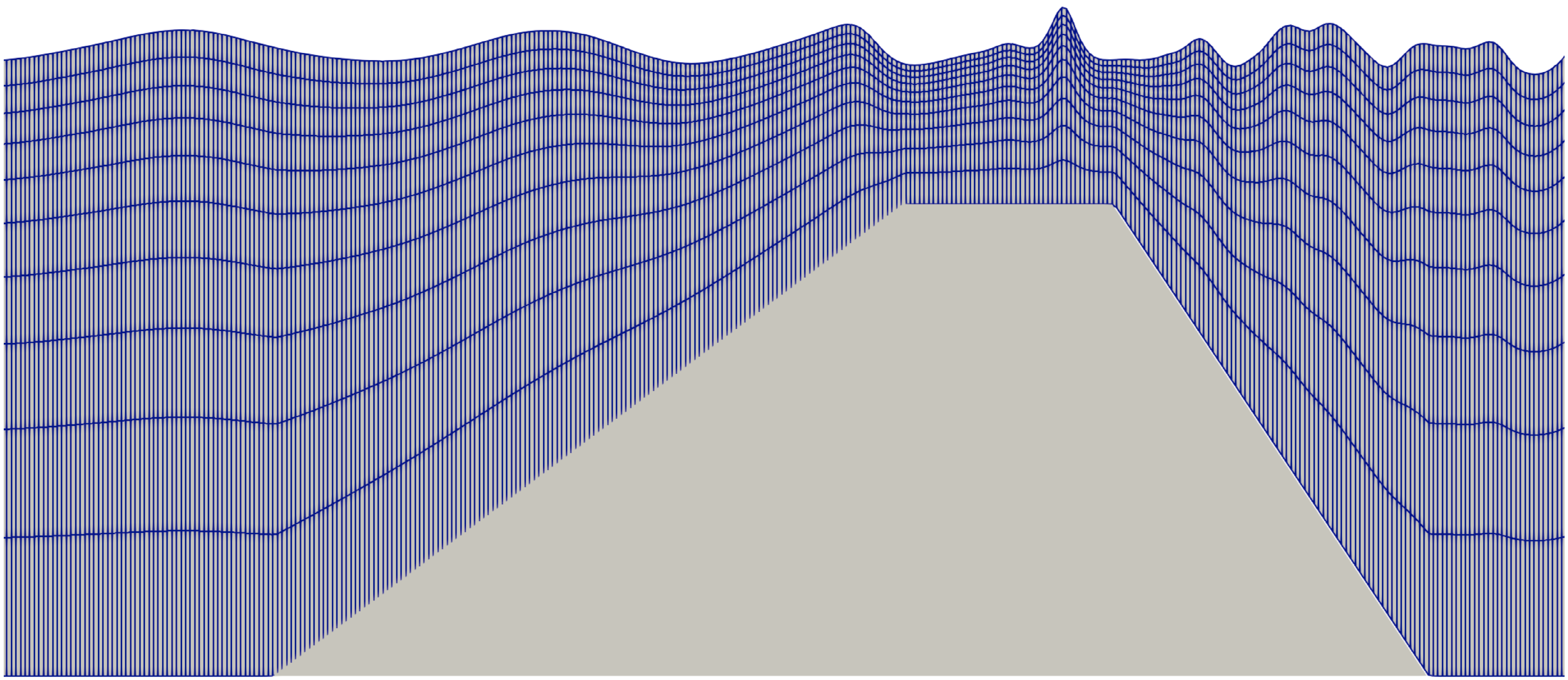
$$\frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} + \frac{\partial^2\phi}{\partial z^2} = 0$$

$$\frac{\partial \eta}{\partial t} = -\frac{\partial \eta}{\partial x}\frac{\partial \widetilde{\phi}}{\partial x} - \frac{\partial \eta}{\partial y}\frac{\partial \widetilde{\phi}}{\partial y} + \widetilde{w}\left(1 + \left(\frac{\partial \eta}{\partial x}\right)^2 + \left(\frac{\partial \eta}{\partial y}\right)^2\right), \quad z = \eta$$

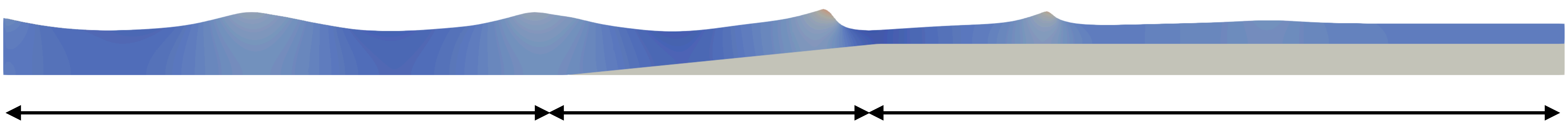
$$\frac{\partial \widetilde{\phi}}{\partial t} = -\frac{1}{2}\left(\left(\frac{\partial \widetilde{\phi}}{\partial x}\right)^2 + \left(\frac{\partial \widetilde{\phi}}{\partial y}\right)^2 - \widetilde{w}^2\left(1 + \left(\frac{\partial \eta}{\partial x}\right)^2 + \left(\frac{\partial \eta}{\partial y}\right)^2\right)\right) - g\eta, \quad z = \eta$$

$$\frac{\partial \phi}{\partial z} + \frac{\partial h}{\partial x}\frac{\partial \phi}{\partial x} + \frac{\partial h}{\partial y}\frac{\partial \phi}{\partial y} = 0, \quad z = -h$$

Grid arrangement - sigma-coordinate



Numerical setup



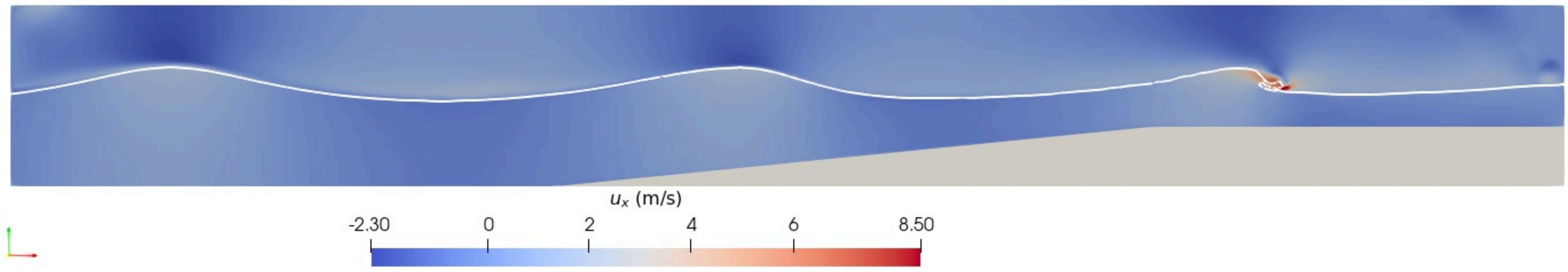
CFD	21.0 m	23.0 m	20.0 m
FNPF	42.0 m	23.0 m	51.0 m
HDC	— m	23.0 m	10.0 m

H=1.30 m T=4.0 s d=3.80 m m =1:10 m

Kamath et al. (2016) Ocean Engineering

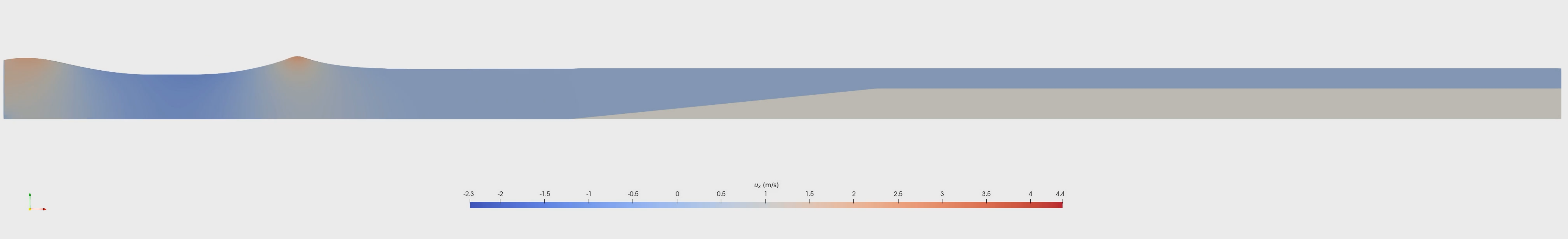
Choi et al. (2015) Ocean Engineering

2D CFD wave tank



50 s of simulation in 1 hr on 128 procs, 130k cells
eq. 16 h on 8 proc laptop

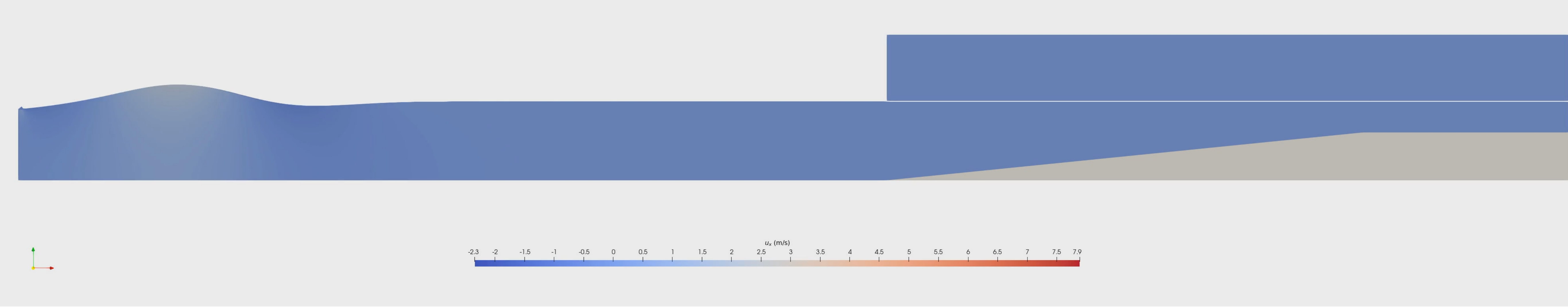
2D FNPF wave tank



100 s of simulation in 294 s on 8 procs laptop, 41760 cells

380 times faster

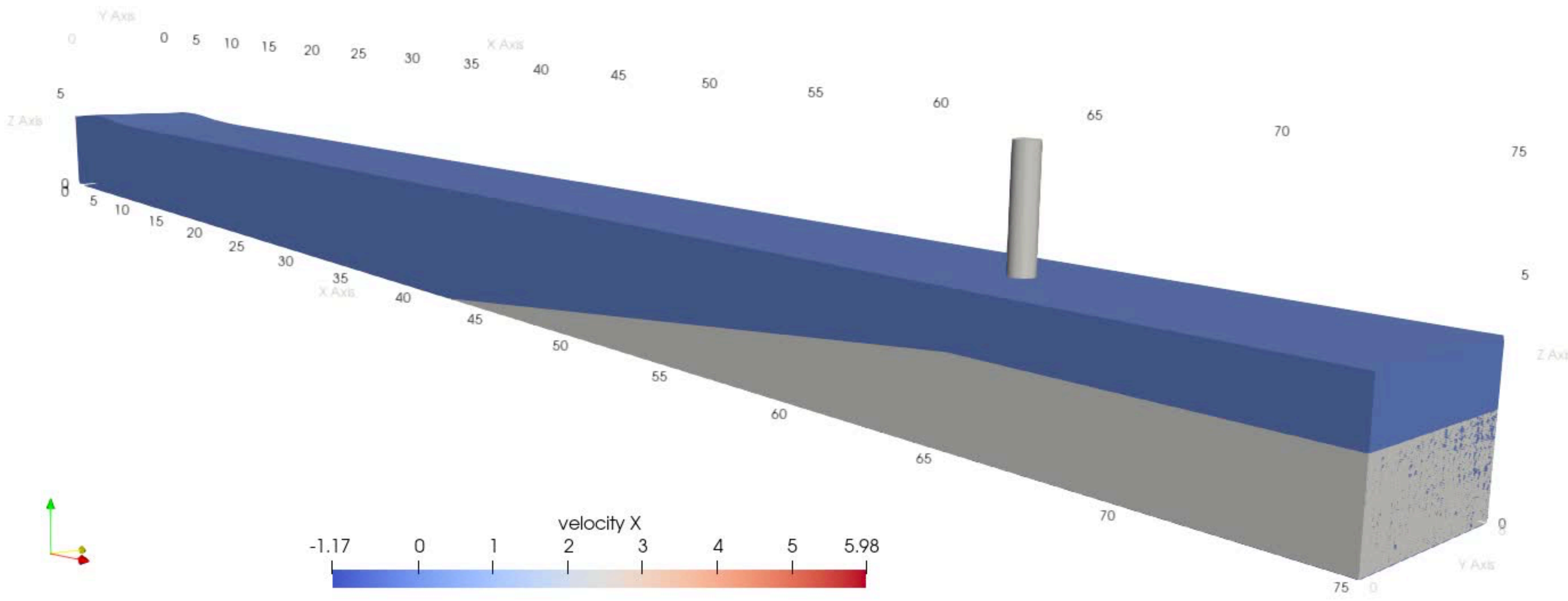
2D FNPF-2D CFD HDC wave tank



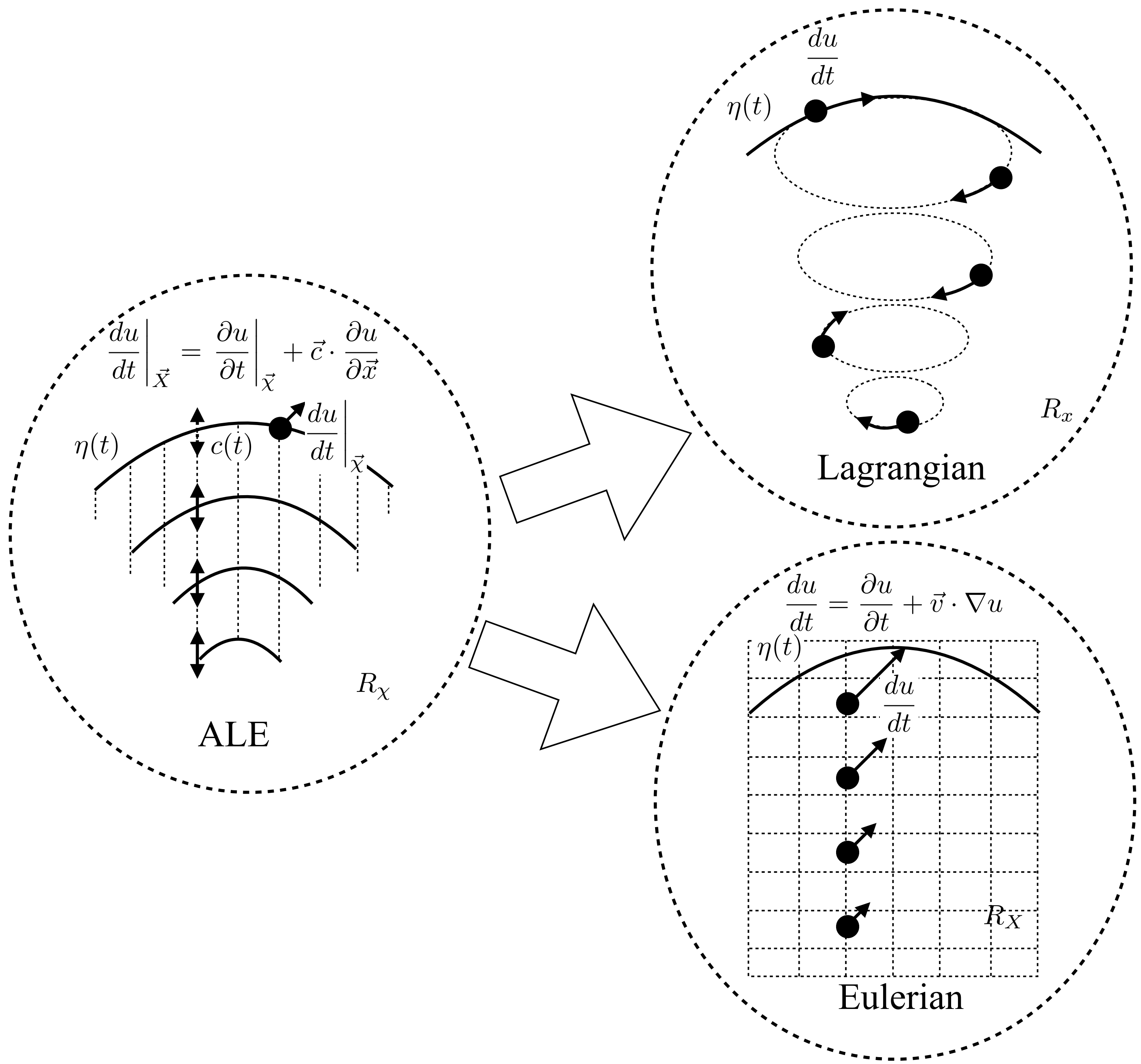
100 s of simulation in 294 s on 8 procs laptop

CFD HDC: 50 s of simulation in 30 mins s on 128 procs
eq. 8 hr on 8 procs laptop

2D FNPF-3D CFD HDC wave tank

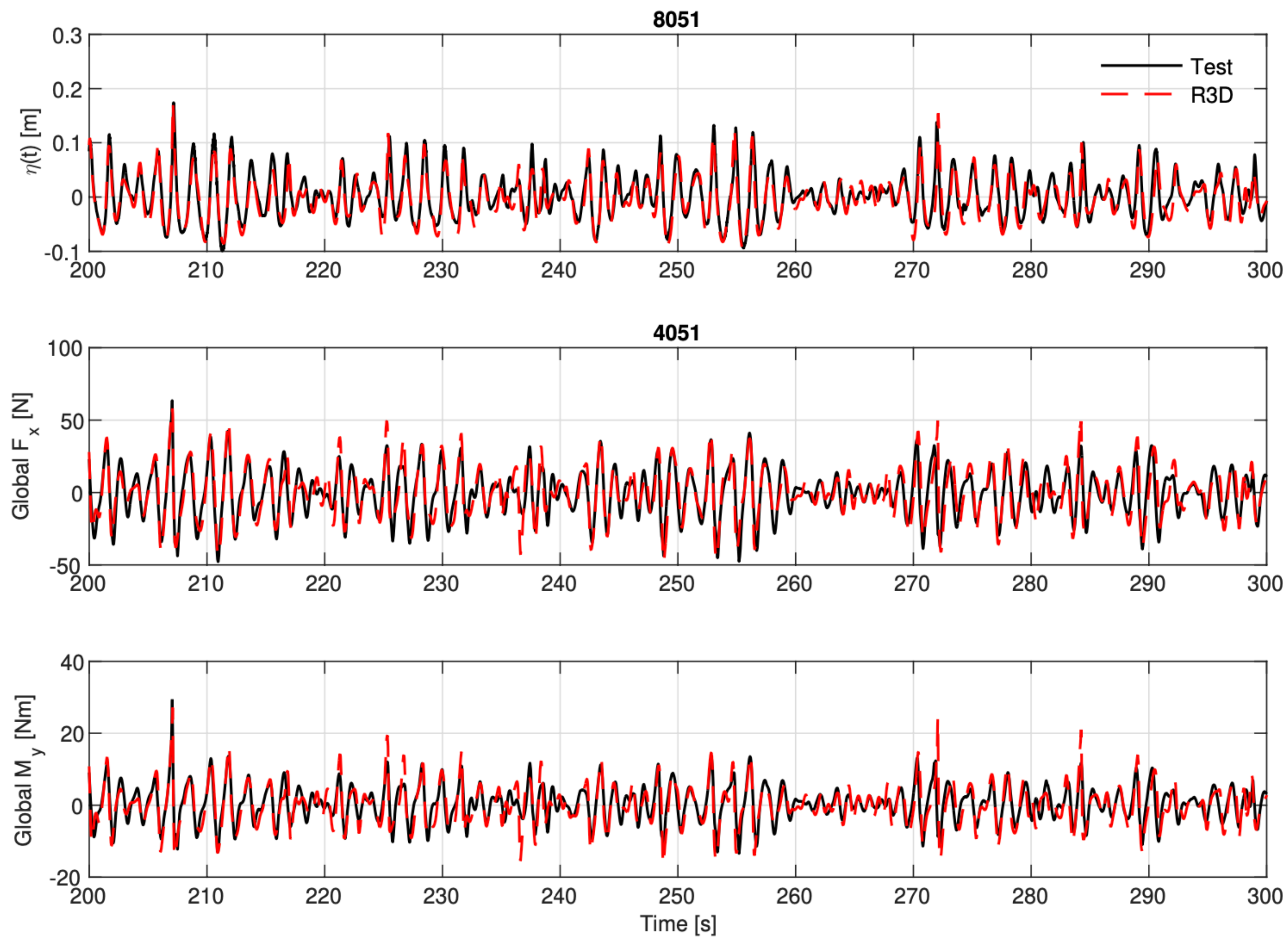


ALE approach



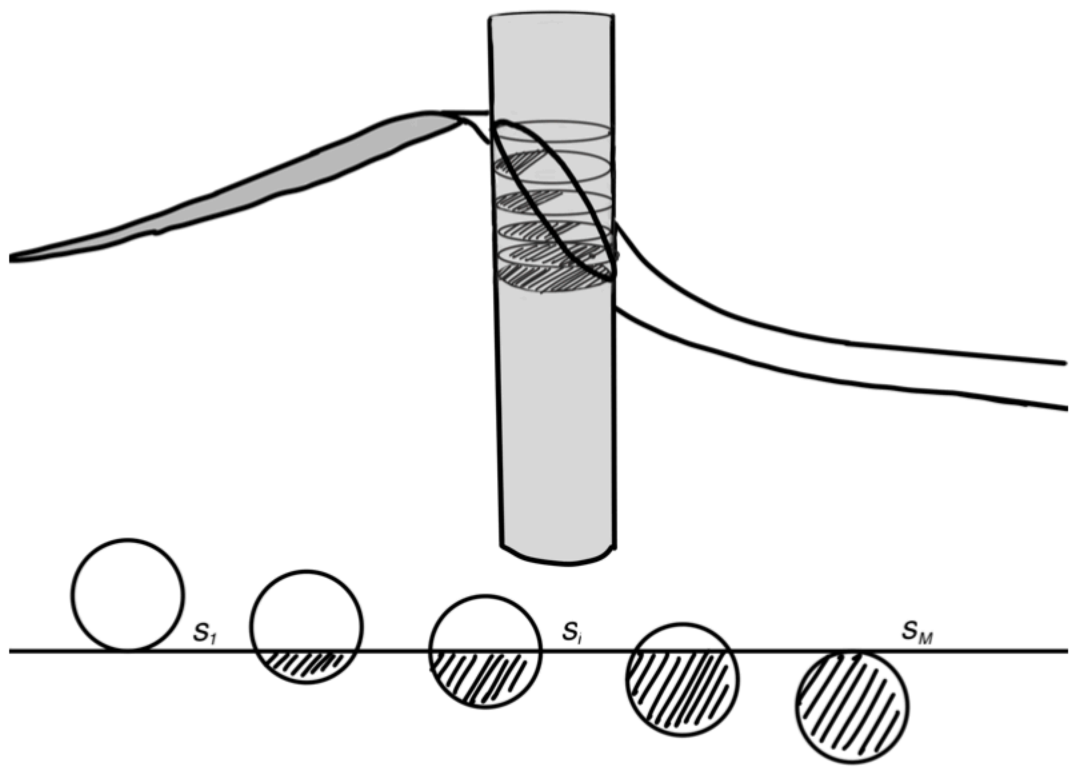
Pákozdi, C., Kamath, A., Wang, W., & Bihs, H. (2022). Application of Arbitrary Lagrangian–Eulerian strips with fully nonlinear wave kinematics for force estimation. *Marine Structures*, *83*, 103190.

ALE approach



$$F_x = \rho\left(h+\eta(x,t)\right)\left[\int_0^1 C_M a_x A_{xy} d\sigma + \int_0^1 C_D u|u|\frac{1}{2}B_p d\sigma\right]$$

Slamming force



$$C_S(s) = 5.15\left[\frac{D}{D+19s} + \frac{0.107s}{D}\right].$$

$$F_S(t) = \int_{z(s_1)}^{z(s_M)} f(z,t)\mathrm{d}z = \int_{z(s_1)}^{z(s_M)} \frac{1}{2}\rho C_S(s(x_i))Du(x_i)\left|u(x_i)\right|\mathrm{d}z \quad (29$$

Pakozdi, C., Kamath, A., Wang, W., Martin, T., & Bihs, H. Efficient Calculation of Spatial and Temporal Evolution of Hydrodynamic Loads on Offshore Wind Substructures. In *International Conference on Offshore Mechanics and Arctic Engineering, OMAE21*.

Summary

The need:

- Industry and education require high-efficiency approach

The approach:

- High-efficiency model - REEF3D::FNPF
- Hydrodynamic coupling (HDC) - REEF3D::FNPF🤝REEF3D::CFD
- Arbitrary Lagrangian-Eulerian (ALE) force calculation in REEF3D::FNPF

The results:

- Wave environment + extreme events + force calculation on laptops
- All students from coastal engineering (Kystteknikk) course (TBA4270) can use SWAN and REEF3D on graduation.